DERMAL SENSITIVENESS TO GRADUAL PRESSURE CHANGES.

BY G. STANLEY HALL AND YUZERO MOTORA.

Τῇδε δοκῶ ζητοῦσι φανεῖσθαι. ἀνάτη πότερον ἐν πολὺ διαφέρουσι γίγνεται μᾶλλον ἢ ὀλίγον;

'Εν τοῖς ὀλίγον.

'Αλλά γε δὴ κατὰ σμικρόν μεταβαίνων μᾶλλον λήσεις ἐλθὼν ἐπὶ ἐναντίον ἢ κατὰ μέγα.

Πῶς δ' οὔ;

PHAEDRUS.
Stallbaum, ed. IV, p. 160.

Fontana observed that when a very slight pressure was applied directly to an excised motor nerve it might be made to increase so gradually as to crush the nerve without causing its muscle to contract. Afanasieff and Rosenthal found also that temperature might be increased and decreased so gradually as to kill a motor nerve trunk without stimulating it. Ritter and others since have found that the electric current has no effect if the density of the current is made to vary slowly enough. Heinzman[1] undertook a more serious experimental solution of the question whether a thermal stimulus could increase so gradually as to be unobserved by the sensory nerves so that death would finally supervene without any movement of either resistance or escape on the part of the animal. Frogs were heated (*a*) locally with a leg in water gradually warmed, and (*b*) totally by sitting on a cork floating in a cylinder of water, though it was much harder to boil intact and normal than brained or reflex frogs without sensation enough to cause motion. Their sensory seemed to

[1] Weber die Wirkung sehr allmäliger Aenderungen thermischer Reitze auf die Empfindungesnerven. Archiv für die gesammte Physiologie. Bd. VI (1872) S. 222.

conform to motor nerves in this respect. Fratscher[1] repeated these experiments, heating very gradually, by means of a lamp applied to the small bulbous end of a tube communicating with the large vase of water in which the animals were exposed, and found he could even induce rigor mortis in normal frogs by immersing only a small portion of the body in the fluid. Acid and alkali stimuli he found might also be applied so gradually as to kill the tissues without stimulating movement. The researches of W. T. Sedgwick,[2] to whose discussion of the topic the reader is referred, seem to show conclusively that in the case of heat this cannot be due to a diminished irritability of the spinal cord by reason of the heat carried into it by the blood, and that organs with a basis of protoplasm cannot so far reverse its laws as to completely lose functional power with no preliminary phase of increased activity.

Quite apart, however, from the question of painless death in such cases the problem of the gradual differentiation of sensation, though so little explored, abounds in practical and theoretical implications of great interest, and a series of determinations was begun here in 1884 upon the pressure-sense according to the following method: A balance, devised and made expressly for this purpose, consisted of a solid iron base and a strong brass beam seventy-two centimetres long, hung on a steel edge and sensitive enough to be far beyond the limit of differential perception with the initial weights used. Along the whole length of the beam runs an edged iron plate,

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[1]Weber continuirliche und langsame Nervenreizung; Jenaische Zeitschrift. N. F. I. 1. (1875) S. 130.

[2]On the variation of reflex excitability in the frog induced by changes of temperature. Studies from the Biological Laboratory of the Johns Hopkins University, 1882. Page 385.

made very true, to serve as the track for a truck, from which was suspended a little platform to carry weights. To this was attached a long horizontal band running about the drum of a kymograph, which we used as a motor on account of its approximately uniform rate of motion, changes in the latter being found, by careful measurement, so small within the times we used that they could be disregarded. The contact of the knife edge, on which the balance was pivoted, with its support, the center of the pivots of the wheels on the truck, and the application of the force by means of the band, were all on the same level, and by this means the effects of traction on the free oscillation of the balance were so slight that sudden reversals of the direction of motion, which could be brought about instantly at any time by a key described in a previous communication [Mind, No. XL., page 557], did not sensibly affect it. The car, which, after careful experiments with flowing sand (which suggests how irregular the best hour-glasses must have been), was found to be much more reliable, may thus travel along the entire length of the beam, and bearing any weight placed on its platform, at any rate in which the drum can be set in motion, and a pointer which it carries may be made to pass over the divisions of the millimetre-scale on the track to the beat of a metronome. Certain suitable velocities and weights with the rate of increment of pressure per second were carefully predetermined. Under one end of the beam was a metalic button, any size of which could be used, which was covered with rubber to eliminate temperature sensations—a matter which, where the contact of such an arrangement is for so long times, must be con-

stantly regarded—by which the pressure was applied to the skin, and on the other end of the beam was a small table with fixed positions for counterweights, by which, together with the position of the car, which could be started at its full velocity at once, the amount of initial pressure was determined. To minimize oscillations the counterweight was removed by means of a cam.

The mode of making observations upon the volar tip of the index finger, *e. g.*, is as follows: The arm is rested on a comfortable support, the hand turned upward and the eyes closed. A special receptacle is made to fit the whole surface of the nail into which it is laid just under the button, which is brought down to within a millimetre of it by a screw supporting the other overweighted end of the beam. At a signal the counterweight is lifted by the cam, and after a fixed interval of from one to four seconds, during which all oscillations, if there be any, has ceased, by a turn of the key the car begins to move without noise or jar, and the differentiation begins, while the time, involving the amount of increase or decrease of weight, is recorded by a metronome till the percipient decides whether the weight is increasing or decreasing and signals to stop the apparatus, and says plus or minus accordingly. The wrong judgments by all observers throughout were found to be so very rare that they have been disregarded. The protocol thus gives us the point of application (commonly the tip of the left forefinger), the initial weight, the absolute amount of pressure increase or decrease per second, and the time required for a judgment. As the experimentations progressed the two chief causes of variation, viz.: changing degrees of attentives and of certainty, steadily diminished.

TABLE I.

	5	10	20	30	40	50	60	65	70	75	80	85	100	200	500
H. B. N........		16.05 +14.06 —18.10	13.08 +11.91 —14.23	14.26 +12.25 —16.12	10.16 +8.17 —12.	7.36 +7.23 —7.5				4.02 +3.54 —4.5	3.14 +3.17 —3.11	5.4 +5.3 —5.5	5.26 +4.28 —6.23	6.1 +5.4 —6.9	
H. N...........	17.4 +18.4 —16.4	13.37 +13.1 —13.65	12.3 +11.5 —13.1	10.8 + 9.9 —11.9	7.5 +6.5 —8.5	8.2 +7.9 +8.5				6.65 +5.7 —7.6			6.15 +5.1 —7.2	7.25 +6.1 —8.4	
E. H. B........	16.7 +15.8 —17.6	7.42 +7. —7.8	6.02 +5.7 —6.2	5.22 +4.7 —5.7	5.82 +4.9 —6.8	7.88 +6.8 —8.7				8.3 +8. —8.6			5.67 +5.54 —5.8	7.7 7.5 —7.9	
J. M............	15.95 +15.40 —16.30	9.05 +8.4 —9.7	11.05 +9.8 —12.3	7.5 +7.8 —7.2	10.05 +8.7 —11.4	11.4 +8.2 —14.6	10.45 +8. —12.9						12.45 +10.3 —14.6	10.75 +8. —13.5	
Y. M..........	22.1 +23.9 —20.3	16.1 +16.4 —15.8	12.12 +13.26 —11.04	8.23 +9.05 —7.4	10.41 +11.7 —9.12	8.11 +9.12 —7.1	7.3 +6.7 —7.8	6.96 +7.3 —6.7	6.88 +6.6 —7.4	7.28 +7.2 —7.3			8.77 +8.4 —9.15	8.4 +6.9 —9.9	10.21 +7.31 —13.12
C. H.....	6.85 +7.50 —6.2	8.05 +8.1 —8.	8.25 +7.5 —9.	8.75 +8.7 —8.8	9.5 +9. —10.	8.35 +7.5 —9.2				12.35 +10.10 —14.60			14.05 +13.3 —14.8	+13. +11.8 —14.2	

In the preceding table the upper horizontal line expresses the initial weight in grammes. The rate of differentiation per second is always $\frac{4}{125}$ of this. The numbers are seconds and fractions of seconds. Of the signs prefixed plus denotes increase of weight and minus decrease, the numbers above with no sign being the average of the two below. Each number is an average, of twenty single experiments. Thus, with an initial weight of five grammes, where the rate of differentiation would be 0.16 grammes per second, it takes Y. M. 22.10 seconds to make up his mind with confidence whether the change of pressure he knows from the signal is taking place, is an increase or a decrease, while J. M. decides in 15.45 seconds.

TABLE II.

	$\frac{16}{125}$	$\frac{8}{125}$	$\frac{4}{125}$	$\frac{2}{125}$	$\frac{1}{125}$	$\frac{1}{250}$	$\frac{1}{500}$
H.B.N.		3.28 +3.25 —3.31	7.36 +7.23 —7.50	9.36 +9.23 —9.50	15.29 +14.67 —16.00	20.36 +19.00 —21.83	
H. N.	3.70 +3.80 —3.60	5.55 +5.40 —5.70	8.20 +7.90 —8.50	8.15 +7.65 —8.65	12.50 +11.90 —13.10	21.50 +21.33 —21.71	
E.H.B.	3.05 +3.10 —3.00	5.40 +5.40 —5.30	7.88 +6.80 —8.70	8.48 +7.66 —9.23	9.96 +9.25 —10.60	14.68 +14.91 —14.46	
J. M.		6.45 +4.1 —8.6	11.4 +8.6 —14.6	9.9 +10.2 —9.6	11.7 +11.2 —12.2	21.2 +20.5 —21.9	80. +85. —75.
Y. M.	3.43 +3.44 —3.42	4.58 +4.93 —4.36	8.10 +9.12 —7.10	11.65 +9.88 —12.98	22.76 +21.00 —24.40	34.04 +31.60 —37.80	66.00 +67.00 —65.00
C. H.	4.40 +4.80 —4.00	4.85 +5.10 —4.60	5.25 +5.10 —5.40	5.85 +6.10 —5.60	7.40 +7.10 —7.70	7.60 +8.00 —7.20	

In Table II the initial or threshold weight is constantly 50 grammes, which from Table I seems about the most favorable for all individuals for further exploring the psycho-physic relation here, and the rate of differentiation varies from $\frac{16}{125}$ to $\frac{1}{500}$ of this threshold value per second, the numbers as before representing seconds and each expressing an average of twenty single records.

TABLE III.

	5	10	20	30	40	50	60	65	70	75	80	85	100	200	500
		5.14	8.37	13.69	13.	11.77				9.6	8.04	14.69	16.83	39.04	
H. B. N........		+4.5	+7.62	+11.76	+10.46	+11.57				+8.5	+8.12	+14.42	+13.69	+34.56	
		−5.8	−9.1	−15.47	−15.36	−12.				−10.8	−7.96	−14.96	−19.93	−44.16	
	2.78	4.28	7.87	10.37	9.6	13.12				15.96			19.68	46.4	
H. N...........	+2.96	+4.19	+7.36	+9.05	+8.32	+12.64				+13.68			+16.32	+39.04	
	−2.64	−4.37	−8.38	−11.42	−10.88	−13.6				−18.24			−23.04	−53.76	
	2.67	2.37	3.85	5.01	7.45	12.6				20.04			18.11	49.28	
E. H. B........	+2.63	+2.49	+3.65	+4.51	+6.27	+10.88				+19.2			+17.73	+48.	
	−2.83	−2.24	−3.97	−5.47	−8.70	−13.92				−20.64			−18.56	−50.56	
	2.55	2.89	7.07	7.02	12.86	18.24	20.06						39.84	72.	
J. M......	+2.61	+2.69	+6.27	+7.49	+11.13	+13.12	+15.36						+32.96	+51.2	
	−2.46	−3.10	−7.87	−6.91	−14.6	−23.36	−24.77						−46.72	−86.4	
	3.5	5.15	7.75	7.9	13.32	12.97	14.02	14.48	15.41	17.49			27.87	54.4	163.36
Y. M...........	+3.8	+5.24	+8.48	+8.69	+14.98	+14.59	+12.86	+15.18	+14.78	17.28			+26.88	+42.88	+116.96
	−3.2	−5.05	−7.06	−7.1	−11.77	−11.37	−14.98	−13.94	−16.57	17.52			−29.28	−63.36	−209.92
	1.09	2.58	5.28	8.4	12.16	13.36				29.64			44.96	83.2	
C .H..........	+1.20	+2.59	+4.8	+8.35	+11.52	+12.				+24.24			+42.56	+75.52	
	− .99	−2.56	−5.76	−8.45	−12.8	−14.72				−35.04			−47.32	−90.88	

In Table III. the upper horizontal line represents initial weights in a series of observations, the differentiations being always $\frac{4}{125}$ of the threshold per second. The figures of the table represent the grammes and fractions of a gramme it was found necessary to add or subtract before the difference was perceived. This was calculated from the first table.

TABLE IV.

	5	10	20	30	40	50	60	65	70	75	80	85	100	200	500
H. B. N.		1.51	1.42	1.45	1.32	1.23				1.13	1.1	1.77	1.17	1.19	
		+1.45	+1.38	+1.39	+1.26	+1.23				+1.11	+1.1	+1.77	+1.14	+1.17	
		−1.58	−1.45	−1.51	−1.38	−1.24				−1.14	−1.09	−1.78	−1.2	−1.22	
H. N.	1.56	1.43	1.39	1.34	1.24	1.26				1.21			1.19	1.23	
	+1.59	+1.42	+1.36	+1.31	+1.2	+1.25				+1.18			+1.16	+1.19	
	−1.53	−1.44	−1.41	−1.38	−1.27	−1.27				−1.24			−1.23	−1.28	
E. H. B.	1.53	1.24	1.19	1.17	1.19	1.25				1.27			1.18	1.25	
	+1.52	+1.25	+1.18	+1.15	+1.15	+1.22				+1.25			+1.18	+1.24	
	−1.56	−1.22	−1.20	−1.18	−1.22	−1.28				−1.28			−1.18	−1.25	
J. M.	1.51	1.29	1.35	1.24	1.32	1.36	1.33						1.4	1.36	
	+1.52	+1.27	+1.31	+1.25	+1.28	+1.26	+1.25						+1.33	+1.25	
	−1.49	−1.31	−1.39	−1.23	−1.36	−1.46	−1.14						−1.47	−1.43	
Y. M.	1.7	1.51	1.37	1.26	1.33	1.25	1.23	1.22	1.22	1.23			1.28	1.27	1.31
	+1.76	+1.52	+1.42	+1.29	+1.37	+1.29	+1.41	+1.23	+1.21	+1.23			+1.27	+1.21	+1.23
	−1.64	−1.50	−1.35	−1.23	−1.29	−1.22	−1.25	−1.21	−1.23	−1.23			−1.29	−1.31	−1.42
C. H.	1.22	1.26	1.26	1.28	1.3	1.27				1.39			1.45	1.41	
	+1.25	+1.26	+1.24	+1.28	+1.29	+1.24				+1.32			+1.43	+1.37	
	−1.20	−1.26	−1.28	−1.28	−1.32	−1.29				−1.46			−1.47	−1.45	

The fourth table represents the ratio between the threshold and the numbers expressed in the third table. In that table it was necessary for an initial weight of 5 grammes to be differentiated to the amount of two and seventy-eight hundredths grammes in order that the difference should be perceived by H. N., and five is to this number as twenty to fifty-six hundredths, as is shown in Table IV.

Table V.

	$\frac{16}{125}$	$\frac{8}{125}$	$\frac{4}{125}$	$\frac{2}{125}$	$\frac{1}{125}$	$\frac{1}{250}$	$\frac{1}{500}$
H.B.N.		10.49 +10.4 —10.59	11.77 +11.57 —12.	7.49 +7.38 —7.6	6.12 +5.86 —6.40	4.07 +3.8 —4.36	
H. N.	23.64 +24.32 —23.04	17.76 +17.28 —18.24	13.12 +12.64 —13.6	6.52 +6.12 —6.92	5. +4.76 —5.24	4.3 +4.26 —4.34	
E.H.B.	19.52 19.85 19.20	17.28 +17.60 —16.96	12.6 +10.88 —13.92	6.78 +6.13 —6.38	3.98 +3.7 —4.24	2.94 +2.98 —2.89	
J. M.		20.45 +13.12 —29.46	18.24 +13.12 —23.36	7.92 +8.16 —7.68	4.68 +4.48 —4.88	4.24 +4.1 —4.38	8. +8.5 —7.5
Y. M.	21.95 +22.02 —21.88	14.59 +15.78 —13.95	12.96 +14.5 —11.37	9.32 +7.9 —10.38	9.14 +8.4 —9.76	6.8 +6.32 —7.56	6.6 +6.7 —6.5
C. H.	28.16 +30.72 —25.60	15.52 +16.32 —14.72	8.41 +8.16 —8.64	4.68 +4.88 —4.48	2.96 +2.84 —3.08	1.52 +1.6 —1.44	

TABLE VI.

	$\frac{16}{125}$	$\frac{8}{125}$	$\frac{4}{125}$	$\frac{2}{125}$	$\frac{1}{125}$	$\frac{1}{250}$	$\frac{1}{500}$
H.B.N.		1.21 +1.22 —1.23	1.23 +1.23 —1.24	1.15 +1.15 —1.15	1.12 +1.11 —1.13	1.08 +1.08 —1.09	
H. N.	1.47 +1.49 —1.46	1.35 +1.34 —1.36	1.26 +1.25 —1.27	1.13 +1.12 —1.14	1.1 +1.1 —1.1	1.09 +1.08 —1.09	
E.H.B.	1.39 +1.40 —1.38	1.34 +1.34 —1.34	1.25 +1.22 —1.28	1.13 +1.12 —1.14	1.08 +1.07 —1.08	1.06 +1.06 —1.06	
J. M.		1.4 +1.26 —1.43	1.36 +1.26 —1.46	1.16 +1.18 —1.15	1.09 +1.07 —1.10	1.08 +1.08 —1.09	1.16 +1.17 —1.15
Y. M.	1.44 +1.44 —1.44	1.29 +1.31 —1.28	1.27 +1.31 —1.24	1.18 +1.16 —1.20	1.18 +1.17 —1.19	1.13 +1.12 —1.15	1.13 +1.13 —1.13
C. H.	1.56 +1.61 —1.51	1.31 +1.33 —1.29	1.17 +1.16 —1.17	1.09 +1.1 —1.09	1.06 +1.06 —1.06	1.03 +1.03 —1.03	

The fifth table represents the same relations as the third, except that the calculation is based on the experiments of the second table, while the third table is based on the first. The sixth table represents the same relations as the fourth, except that it is based on the fifth as the fourth is based on the third.

These results are presented so clearly in tables IV and VI that graphic representation in terms of ordnates and abscissas is unnecessary. They are more nearly uniform with Y. M., H. N. and H. B. N., while the other three deviate more from these and from each other. A relation very inaccurately approaching the constancy expressed by Weber's law is obvious, but is not only inexact, but appears only within limits themselves also subject to wide individual variations. C. H. (of Tables I and IV *e. g.*) recognizes a

differentiation of a constant rate per second with from as little as five up to from fifty to seventy-five grammes as an initial weight, while H. B. N. does not reach any constancy with an initial weight less than that of the upper limit of C. H. The latter subject (C. H.) was however especially selected from a furniture factory as a polisher and sand-paperer of exquisite pressure sense. This wide range of individual variation, which may be caused by both culture and heredity, may be utilized by anthropological methods, but from the results of experiments in the field of the psycho-physic law most analgous to ours was perhaps hardly to have been expected, at least with students with fingers uncalloused by manual labor.

Compared with the sensibility to differences of pressure determined· by the more faultess of the many experiments with the appreciation of weights successively applied, our results show on the whole less sensitiveness. In some cases a change of $\frac{1}{20}$ or $\frac{1}{30}$ or even less of the initial weight has been perceived while with us, under the most favorable conditions (which seem *e. g.* in Tables II and V to be when a variation of $\frac{1}{250}$ of the initial weight of 50 grammes occurred per second) the judgment responds to a variation of about $\frac{1}{12}$.

In the study of capillary blood pressure in the human skin made by v. Kries,[1] a plate of glass was applied to the dermal surface and its pressure regulated by weights suspended to it below, and the effect, measured by the amount of paling, observed. The different thickness, rigidity and vascularity of the skin, as well as the method of observation, made results by

[1]Uber den Druck in den Blutcapillaren der menschlichen Haut. Ludwig's Arbeiten, 1875.

this method very inexact. Yet the great effect upon capillary pressure produced by raising or depressing the arm, though much less than would be caused by the different positions of the limb, according to hydrostatic laws, was so considerable as to suggest a precaution against possible errors which we observed by keeping the hand at the same relative altitude with reference to the rest of the body. Again, Fechner admits that the pressure sense is liable to errors in that the elasticity of the skin prevents the pressure upon the nerve in terminal organs from corresponding exactly with the weight laid on the skin. The depression of the skin touched by the button was measured by means of a cyclometer by Y. M. for various weights upon his own fingers as follows—

Weight.	Depression.
5 Grammes.	.2151 Millimetres.
10 "	.4992 "
20 "	1.0078 "
30 "	1.3310 "
40 "	1.6784 "
50 "	1.7187 "
100 "	2.7490 "
200 "	3.0616 "

With our apparatus the smallest initial weights used bring the button in contact with the skin over its entire surface, and pressure does not increase the surface of contact as would be the case with a larger button. Increasing weight depresses new skin from a wider and wider area around the surface of contact, and may change the distribution of pressure over this surface, especially as between its centre

and edges. Time is also probably a factor of the amount of depression and expulsion of blood. With the largest weights and longest times used by us, however, there is no distinct indication of insensitiveness increasing with the gradualness of the increment that seems due to local anæmia by pressure. If sensitive human tissue can be crushed without pain by increasing the pressure gradually enough after the analogy of Heinzmann's and Fratscher's experiments with heat applied to normal frogs, or even unusually great pressure-differentiation can be made so gradual as to escape attention when especially directed to it, a different apparatus method of experimentation than that used in this series of observations is needed.

How, then, shall we explain the new relation that appears between the last two columns of Table II.? Here, when the rate of differentiation of a constant initial weight is $\frac{1}{500}$ per second the time is nearly double what it is for a rate of differentiation of $\frac{1}{250}$ per second for Y. M. and nearly quadrupled for J. M. If the law of constant increment held irrespective of time, the numbers in each column should be double those corresponding to them in the column before, which occurs in but one case and approximately only in a very few other sporadic cases. Indeed, even the results of the last column may possibly be sporadic. We should expect however a priori a point somewhere where an increase in the time of applying a differentiation would diminish sensitiveness for it, but that this is reached in the last two columns of Table II., the results are too few to make us certain. Another problem presented by Table II. is to account for the great obtuseness for

differentiations applied at a relatively rapid rate. J. M., *e. g.*, is nearly four times as sensitive to differentiation applied at the rate of $\frac{1}{250}$, of the original weight, as he is when it is applied at the rate of $\frac{8}{125}$ of it per second.

In the best psycho-physic experiments involving the comparison of two weights, they are applied successively, with a definite time for contact, interval of rest, etc.—the application of both weights occupying *e. g.* five seconds—and the attention is then directed to the task of comparing the impression superposed in memory. In pressure, as opposed to lifting tests, little attention has been paid to the speed of application and levitation of the weights. With the second weight we might conceive that cells excited by the first are reëxcited, a few being left out of function, or a few new ones excited, according as the heavier weight comes first or last. By this method of gradual differentiation, however, the acts of comparison and judgment must go on during the process of the change, and the more rapid it is the greater the distraction. The comparison is made between an initial pressure held in memory and a present changing sensation. If memory were merely a faint sensation rapidly loosing intensity, we should have a double differentiation. The remembered initial pressure would fade like an after-image, while the present pressure is constantly increasing, and the differential sensibility would be finer than in the old method. The fact that it is less so cannot be entirely explained by the time required to stop the apparatus after a judgment is made, for that reduces itself in our experiment nearly to the reaction time from ear to hand of the person con-

trolling the drum, for the subject under observation gave the signal to stop the apparatus as soon as he felt a judgment within his reach, as it were, and it was expressed and recorded later. It is obvious, however, that a part, perhaps considerable, of the apparent decrease of sensibility from rapid differentiation is due to this constant error, but not all. Besides the perception-time a longer time is required to relate the two impressions in consciousness. The mind, our subjects think, does not keep or have at any time an image or feeling of continuous increment or decrement, Continuity here seems an impossible perception. The attention rather singles out an instant or degree of pressure and compares it with another instant and degree of pressure still further past (and, in fact, not invariably the period of the initial weight), and an impression arises or does not arise, which it is perhaps quite as correct to speak of as a sensation of difference, with a tolerably clear threshold of its own, as a judgment. Indeed, it seems to be impossible to excite a sensation of continuous increment. Again, with certain initial weights and certain rather rapid rates of differentiation, it is hard not to believe that the sensation changes in quality as it changes in quantity, and it may be impossible, with different tactile organs or fibre-ends at different depths of the skin, to get a quantitive change of entire purity. It is hard, however, to resist the impression that, quite apart from these minimal and inconstant changes of quality, the attention finds it difficult if not impossible to grasp continuity in the form of quantitative or intensive change, but rather that the directness of a graduated series is the basis immediately given, and that continuity is derivative and inferred.

Constancy, or uniformity, (as distinct from continuity), of sensory increment is of course not to be expected here, for it is the stimulus that increases uniformly per second, and the sensation, according to the law of Weber, must increase more slowly. Each second of increase bears a constantly less ratio to the total pressure of the preceding second, and if the pressure is decreasing, is in a larger ratio to it. Thus, as the differentiation goes on, a longer and longer time is necessary to create a given ratio for increasing and a less and less time for decreasing pressures. This fact probably is the chief cause of the rather large average errors for increasing weight. The later seconds effect even less sensory modifications than the first. Both greater sensitiveness and less average error in time might therefore be expected from decreasing pressures. The figures show, however, on the contrary, less sensitiveness and no greater uniformity. The most obvious cause for this result is fatigue. The cells, relieved from the effects of pressure, have been excited longest, while the mind has less interest in vanishing than in augmenting impression, and it is harder to bring the attention to bear on them.

In an interesting study by F. C. Müller,[1] which was begun on the excised nerve-muscle preparations of frogs, but extended to motor and then to sensory human nerves percutaneously excited and pointing to a "neurophysic," in place of the psycho-physic law, the author conceives changed excitability as an essential property of sensation. In the experiments of Wedenskii, and especially of Bowditch[2], whose

[1]Physiologische Studien ueber Phychophysik. Archiv f. Anat & Physiol, 1886. Heft. IV.

[2]Science Aug. 27, 1886.

tests seem as conclusive as they are important, changes due to fatigue cannot be assumed for the nerve fibre, but must be limited to terminal organs, the blood supply of which, as we have seen, is reduced by pressure, and to central cells.'' Our experiments allow no interval for rest and increased sensitiveness between the two degrees of pressure, which give rise to the impression of difference such as intervenes in the application of two successive weights. Where the transition is directly from one degree of stimulus to another, with no temporal interruption, the process cannot be the same as when a period of rest intervenes, or even, as in Müller's experiments, where on the basis of the stimulus of a constant current another stimulus in the form of negative variation is applied. Another complexity, also tending to make decision hard and slow, is that there are really three degrees of pressure to be constantly borne in mind—the original pressure as well as the alternative of increase or decrease—while in the most approved application of Fechner's three methods the problem has but two terms. The method of middle gradation only admits of comparison even in this respect with ours. Thus, in fine, whether we look at the number of terms involved in each verdict of consciousness, fatigue, the nature of the mental activity involved, the results, or every detail of method, we have here a new standpoint for viewing psycho-physic relations, and few if any safe inferences from one to the other between the work of Weber and Fechner and their successors and ours can be trusted. We are here confronted with new problems of great range and importance, which the above preliminary results, very far from solving,

barely suggest. What is the ratio, *e. g.*, between increasing suddenness and decreasing weight in producing a given sensory effect? On the one hand the mind has a horror of what is sudden which may amount almost or quite to kataplexy, which knowledge of law and power of prediction serve to alleviate; and, on the other, great changes, if very gradual, are not only imperceptible, but can only be ascertained by indirect and often very circuitous inference. If we compare the conscious minds of men to balances, some tipping to a greater and some to a less weight, we can only reply to the question why they do not tip to still finer stimuli, like the millionth leaf in Leibnitz's forest, by saying that, on the one hand, a practical threshold relieves it from distractions and irrelevancies and favors concentration by abstraction, or else that nature, as it were, suspects consciousness, and that its too great acuteness has been a disadvantage, and that attention must not be too discriminative nor admitted to all spheres of life. It is at least impossible to see any more contradiction between the law of probabilities and what Fechner would call the threshold theory of life, than between the untonality of octaves played by the wind on an Æolian harp and the same octaves on a piano with a pure untempered scale. Consciousness, in some of its aspects, has an articulating habit of dropping the fingers down upon the strings instead of sliding them along.

The following table gives the result of a series of records with heavy initial pressure and slow rates of differentiation, these being the conditions most favorable to fine discrimination:

TABLE VIII.

	1000.			500.			250.			125.		
	+	0	—	+	0	—	+	0	—	+	0	—
Y. M........	100.	128.	128.	66.	76.	78.	20.	20.	21.	18.	21.	18.
M. G........	88.	92.	104.	38.	—	56.	23.	28.	26.	11.	13.	12.
J. T...... ..	60.	96.	94.	26.	72.	44.	23.	29.	28.	10.	11.	11.
Average...	82.	105.	104.	43.	59.	60.	22.	25.	25.	13.	18.	13.

All the figures in this table are grammes. Those above are the four initial weights, and the rest are grammes of increase rest or decrease before the judgment was made, the rate of differentiation throughout being 0.4 per cent. of the initial weight per second, each figure expressing the average of fifteen single observations, and the grammes under each of the four middle zero columns expressing the differentiation that would have taken place if differentiation there had been. Here again there is a general approximation to a constant ratio. The differential sensibility is finer than with smaller initial weights. With all these weights, and especially the lightest, it takes much longer to perceive rest or a minus quantity. This is expressed less, however, in the table above than in the following table of errors—

TABLE IX.

	0 = +	— = 0
1000.......	4.	42.
500.......	40.	38.
250.......	24.	21.
125.......	9.	10.

The figures in the above table express the per cent. of mistaken judgments, (calculated for not far

from fifty single judgments each.) Rest, *e. g.*, is judged to be increase in forty-five per cent. of the cases with an initial weight of 1,000 grammes, and decrease is judged to be rest in forty-two per cent. of cases with its same initial weight. These may be called errors of overestimation, and all errors of underestimation are comparatively rare, as are errors of overestimation when decrease is judged to be increase. That we should be insensitive to decrease was expected from fatigue and expulsion of blood caused by so heavy weight. That rest should so often seem to be increase may be due to gathering energy of attention or perhaps to the progressive action of heavy pressures upon the circulation in the tissues beneath. The fact that we tend to judge even rest as increase seems here, at least, to have made the result indicate greater sensitiveness to increase than if it had been practicable to start the differentiation, to be judged on the basis of the presumptive, slight, constant decrease required to offset this tendency, and which would therefore seem to consciousness to be rest. This constant we designate as the *apparent pressure constant*, and its variation at a given second during the process of an observation we call the *pressure deviation* of that decrease.

In another series of observations the effect of negative pressures or pulls upon the skin of the ball of the left index finger were studied as follows: After a number of trials with various salves and plasters in the market, one was at length found that was sufficiently adhesive, and within the limits of fifty grammes would not crack or give in a way to afford an independent clue to sensation as most do.

The finger nail was then glued to its socket in a heavy block below, and the beam of the balance allowed to swing freely, till, controlled by the position of the car, it came to rest in such a place as exactly to touch, without pressing, the upturned ball of the finger to which it was then also firmly stuck. The car was moved so as to give a very slight but distinct pressure, and then made to travel slowly away from the finger by means of the drum till a sensation of negative pressure, or a pull upward, was detected. It then traveled back till a positive pressure could be felt. Each of these pressures was repeated ten times and then averaged, and then the average of these plus and minus averages taken. This latter might be expected to give the original position of equilibrium of the car empirically determined as above (provided, of course, that the skin is equally sensitive to a push or a pull). The apparent was found, however, to be slightly more negative than the empirical indifference point, determined as above, in each of four subjects. As the pressure gradually changes from a minus to a plus quantity, or conversely, the neutral position is tolerably well marked to consciousness. The sense of contact is present, but without appreciable pressure or pull, as the finger is not absolutely flat even over the small surface of four or five milimetres in diameter, and as tactile experience is rarely with surfaces curved exactly conformably with the shape of the epidermis at rest, as it so nearly is in this case. A sensation of touch over such a surface, which in common tactile experience is impossible without pressure, might be expected to suggest pressure here. Possibly it will be found that it is in-

stinctive compensation for this association that makes a discrepancy between the *real and apparent tactile zero,* as we shall hereafter designate the mechanical and the sensory indifference points, respectively. Even should our further studies find them to coincide, it will be useful to retain both designations.

The apparent tactile zero thus determined is the starting point of our differentiations. The car is drawn to the position corresponding to this position of least sensation, and the percipient, after five seconds rest, hears the signal announcing the start of the car, and is to judge as soon as he can whether the skin is pressed or pulled upward. The sensations for a time are surprisingly indistinguishable. For a moment the change seems decidedly plus, an instant later it appears as certainly minus. The experience is comparable to that of binacular rivalry, where now the picture or color presented to one eye, now that before the other seems to predominate and indeed suggests quantitative determinations in this latter field. For this phenomenon we suggest the name of *antinomous dermal rivalry.* How far, if at all, this may be connected with the fact that every pull depresses the adjacent skin on the sides of the finger (which parts of the skin pressure distends), further studies must make known. On an average finger, disposed as above, a pull of *e. g.,* 20 grammes elevates the skin about three-fourths as much as the same weight depressed it. By referring to the preceding table of cyclometer measurements for the latter, it will thus be seen that in these determinations the beam of our balance has a movement of several millimetres, and emperical deter-

minations showed us that a slight but constant allowance must be made in the weights of the following table for overcoming the variation of the beam of the balance to even these slight changes of position. Making these deductions, we have the following sample of a single day's observations:

TABLE X.

	6.9.		2.6.		0.2.	
	+	—	+	—	+	—
G. S. H.....	12.7	13.3	....	....	7.9	6.9
Y. M.......	16.1	14.4	14 2	12.1	7.3	5.
E. C. S.....	13.	14.3	11.	16.9	8.8	1.2
Average....	13.9	14.	12.6	14.5	8.	7.9

In this table the figures at the top express the amount of differentiation per second in grammes. The figures below are grammes before the judgments of positive or negative pressure, expressed by the signs plus and minus above, were made. Each figure in the table is an average of ten single observations. The numbers are slightly too large, for they represent almost continuous observations with an element of fatigue distributed about evenly, but not eliminated as in fuller tables reserved for the completion of our research on this part of the subject.

The first and chief result of this table is the relatively vast weights involved in differentiation. Aubert and Kammler found the smallest weights that could be perceived when applied to volar finger tip to be from 0.005. to 0.015. gms., and Goldscheider's touch-points are probably at least no less sensitive. Though he did not control the amount of pressure

which he used in determining his pressure points, he was led to distinguish between the sensation of contact and that of pressure,[1] and found even the latter exceedingly sensitive. The literature relating to the psycho-physic law contains almost no reliable tests of pressure between the first observable contact and weights of from six to ten grammes. Strictly speaking, moreover, the sensation of an upward pull upon the skin must not be compared with pressure from within outward along the arterial tracts, or as shown in plethismographic tracings, nor inflammations or throbing sometimes called pounding pains. Nor is the collapse of supportive tissue beneath, which has been suggested as a cause of abnormal dermal sensations, more relevant than the sensations of the elastic skin artists who pull out folds of their skin into dewlaps. In fact, whether negative pressure, although it must favor a different distribution of capillary circulation from a pressure on the same spot, excites any specific sensation other than that of contact (which it may serve to show is specifically different from pressure), and secondary depression by stretching of adjacent dermal tissue, it is idle to conjecture.

On the whole, then, it may be said that, save the older determination of the smallest observable pressure from different parts of the dermal surface, and which since the works of Goldscheider need to be carefully revised, we know at present almost nothing with certainty about pressures below five or ten grammes. As we approach minimal pressures we pass outside the limits of validity for the psycho-

[1]Neue Thatsachen über die Hautsinnnerven; Arbeit für Physiologie, 1885. Supplement-Band, p. 88.

physic law which has prompted most of the modern work in this field. Yet precisely within this realm covered by antinomious dermal rivalry lie the mysterious conditions of the tickle-sense by contact as distinct from the specified and localized tickle-sense, of abnormal excitability passing spontaneously into excitation where we have not yet learned to distinguish subjective from objective sensations, and with respect to which the mind of the adult is still in a rudimentary infantile condition. We also observe here that within these limits the slower differentiations are more finely distinguished. A definite law with regard to the comparative sensibility to pressures and pulls is not yet apparent.

When one index finger is under the button of each end of the balance so that the weight decreases on one finger as it increases on the other, there is no essential increase of sensitiveness, and in some cases a decrease. It requires some time and effort to accommodate the attention alternatively from the finger of one hand to the corresponding finger of the other.